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SUSY Precision Measurements at a Linear Collider

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on behalf of
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SUSY working group

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Introduction

SUSY precision measurements

→ Test of supersymmetry relations

→ Unravel underlying breaking mechanism

SUSY measurements at a LC:

- Clean environment
- High luminosity $L = 500 - 1000$ fb^{-1}
- Polarization of both $e^{\pm}$ beams

Wish list for sparticle hunters:

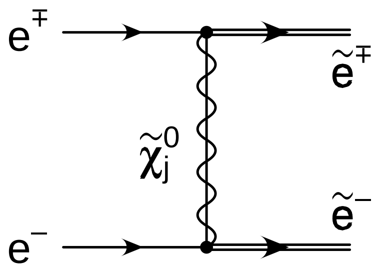
- Quantum numbers, couplings
- Masses
- Sparticle mixing
- $\tan\beta$ and trilinear couplings
- CP violation

This work: focus on precision determination of sfermion properties

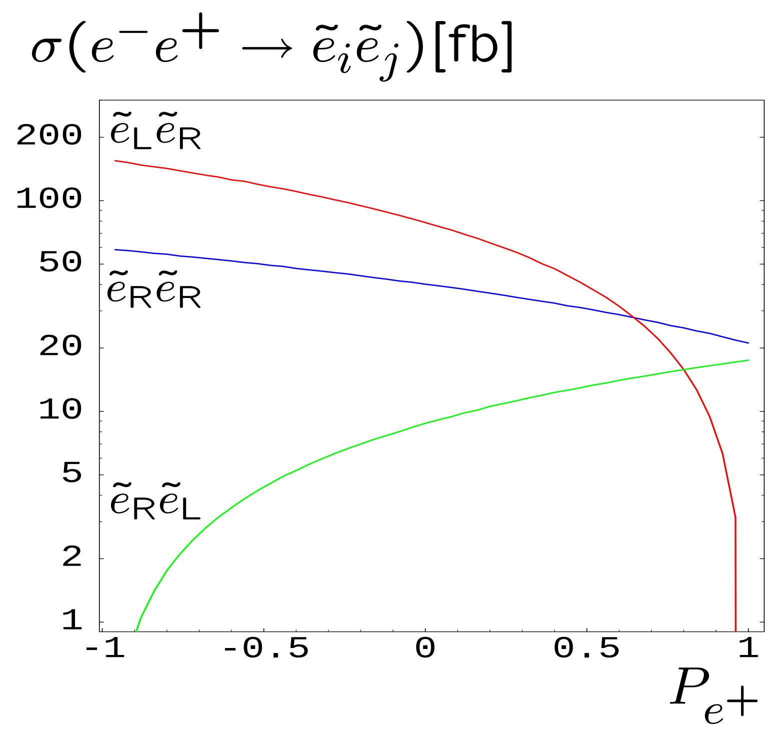
Determination of sfermion quantum numbers

Probe chiral quantum numbers (L/R) of selectrons in
$e^+e^- \rightarrow \tilde{e}_i^+\tilde{e}_j^-$ Blöchinger, Fraas, Moortgat-Pick, Porod '02

t-channel neutralino exchange:



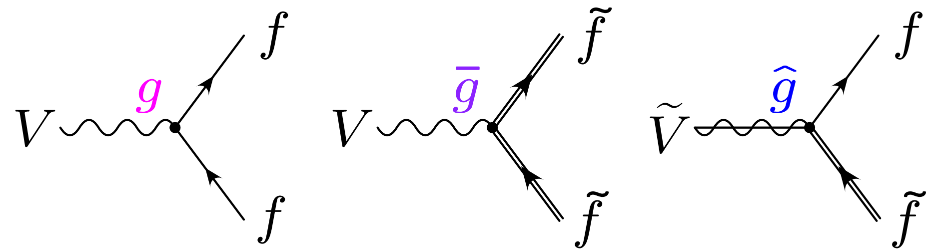
→ Direct relation between incoming beam polarization and outgoing selectron chirality



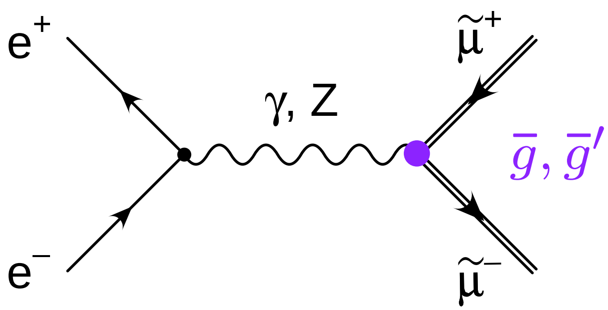
Beam polarization for e^+ *and* e^- beams to suppress s-channel

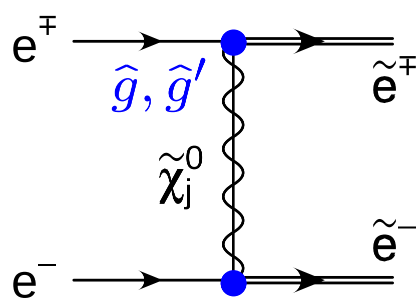
Quantitatively: Determination of sfermion couplings

Fundamental relation
in supersymmetry: $g = \bar{g} = \hat{g}$



Can be tested for electroweak sector in slepton production:





g' U(1) coupl.
g SU(2) coupl.

Cross-section measurementwith 500 fb^{-1} at e^+e^- collider:

$\delta\bar{g}'/\bar{g}' \approx 1\%$ $\delta\hat{g}'/\hat{g}' \approx 0.2\%$
$\delta\hat{g}/\hat{g} \approx 0.7\%$

A.F. '02

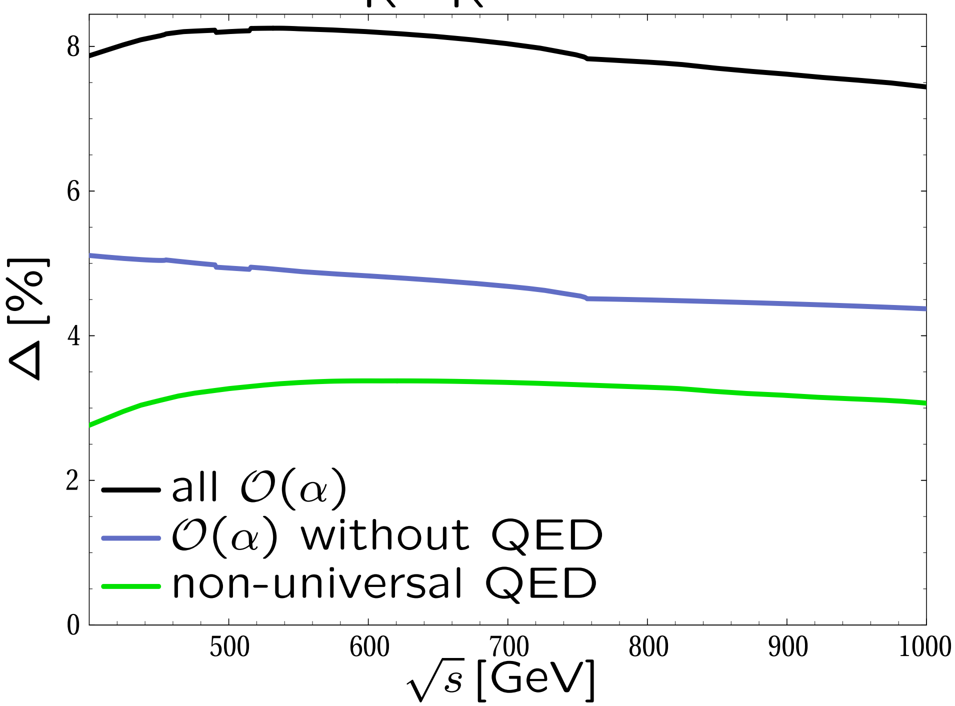
Theoretical uncertainty?!

Radiative corrections to slepton production

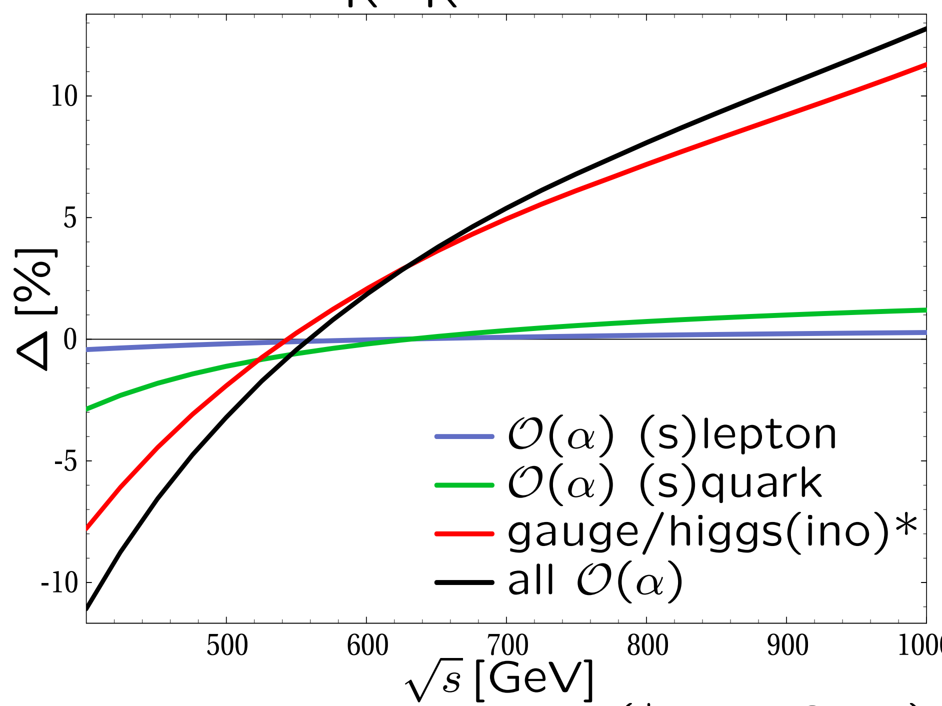
A.F., v.Manteuffel, Zerwas '02

Complete $\mathcal{O}(\alpha)$ corrections in MSSM to $\tilde{\mu}$ and $\tilde{e}$ pair production

$e^+ e^- \to \tilde{\mu}^+_R \, \tilde{\mu}^-_R$



$e^+ e^- \to \tilde{e}^+_R \, \tilde{e}^-_R$ SPS1 scenario



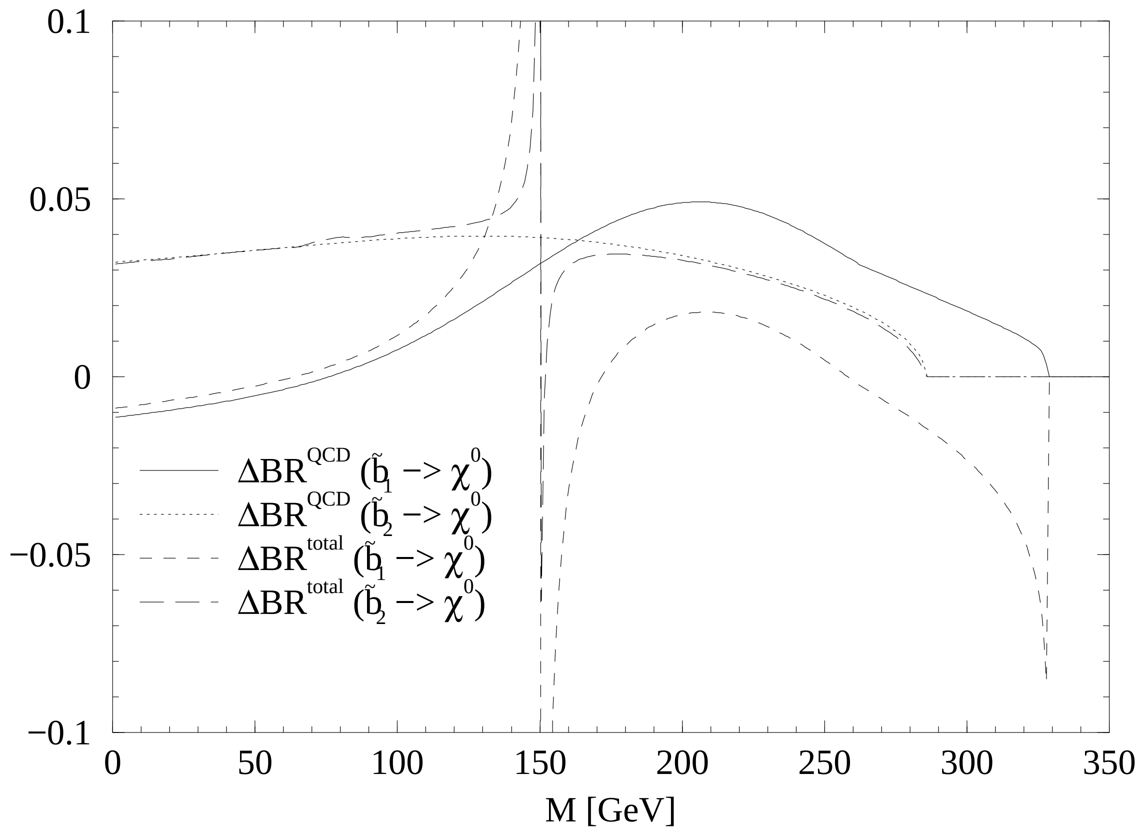
(* incl. QED)

$\to$ Corrections of 5–10%

Radiative corrections to sfermion decay

Complete $\mathcal{O}(\alpha)$ corrections to sfermion decay $\tilde{f} \to f\,\tilde{\chi}_i^0$, $\tilde{f} \to f'\,\tilde{\chi}_j^\pm$

Guasch, Hollik, Solà '01



→ Corrections of 5–10%

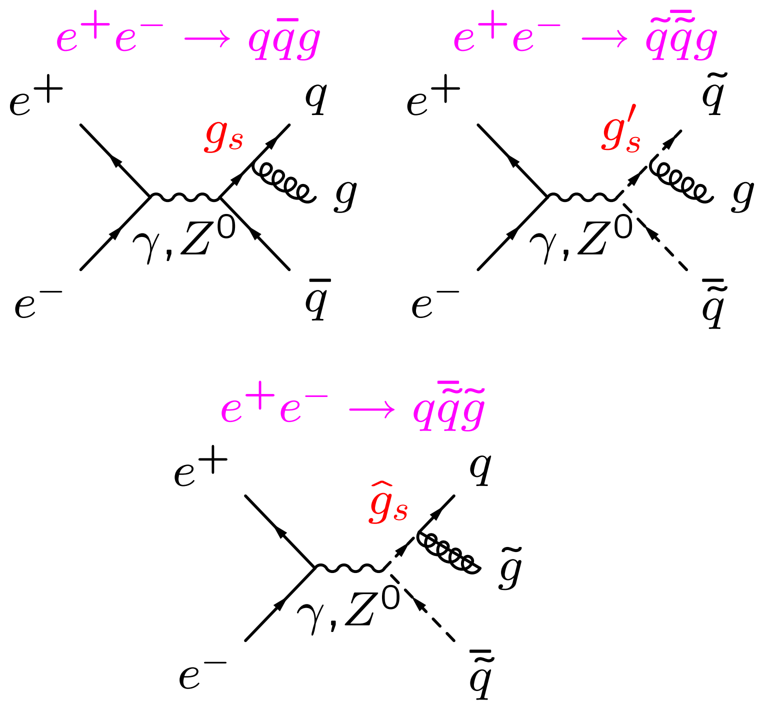
General features of EW corrections to sfermion production and decay:

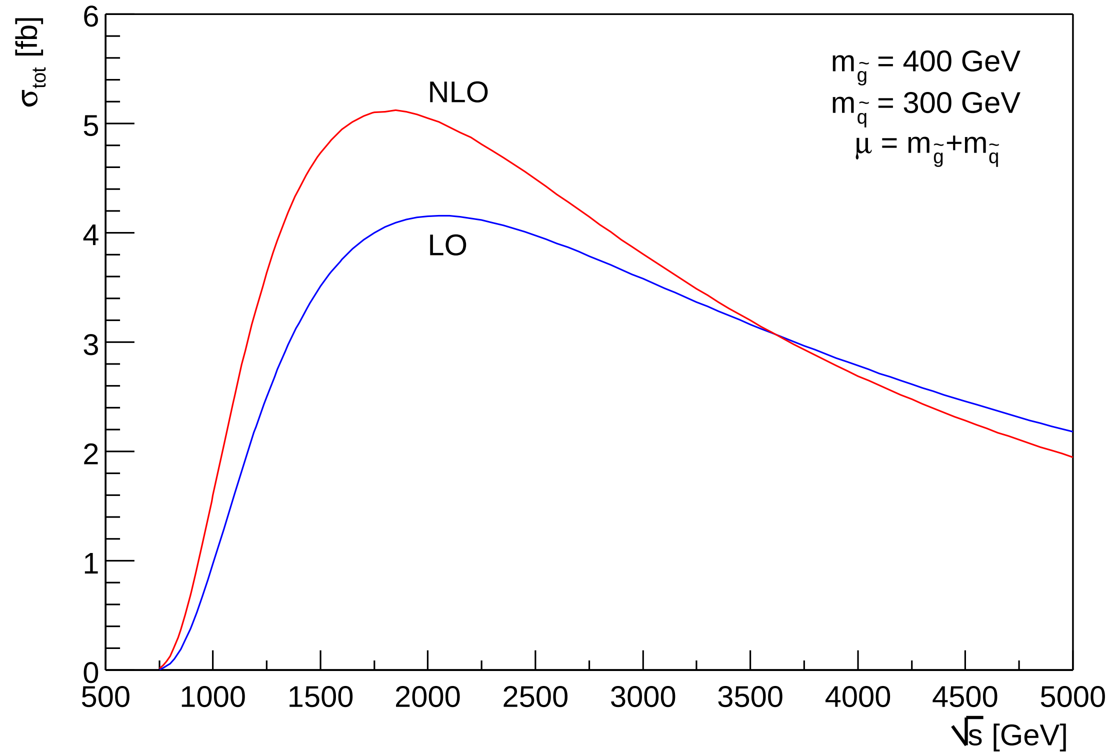
- Sparticles in loops do not decouple: $\frac{\hat{g}_{\text{eff}}}{g_{\text{eff}}} - 1 \propto \log \frac{M_{\tilde{p}}}{Q}, \quad Q < M_{\tilde{p}}$
- Threshold-like corrections
- Renormalization: see e.g. Hollik et al. '02

Testing coupling relations in SUSY-QCD

Brandenburg, Maniatis, Weber, Zerwas '02

Verification of SU(3) coupling relations in associated production at e^+e^- colliders:





- NLO SUSY-QCD corrections enhance cross-sections up to ~20%
- Significant reduction of scale dependence

Sfermion mass measurement

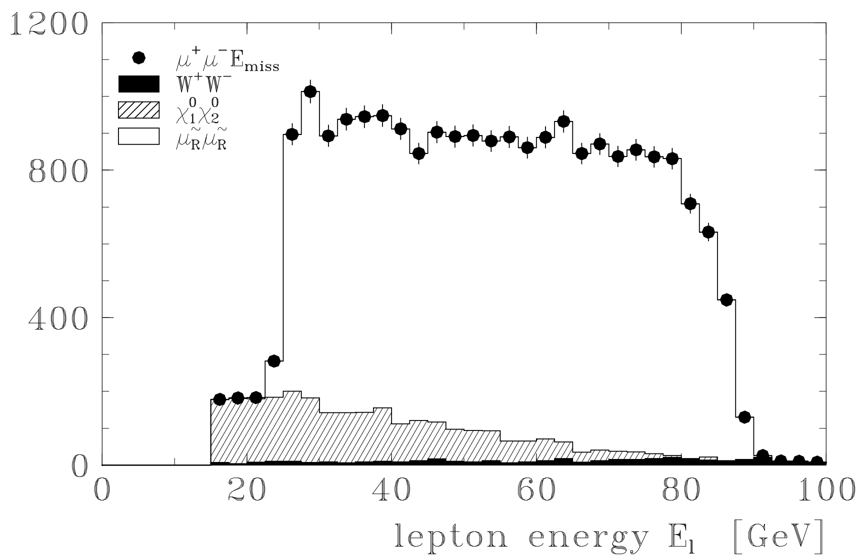
End-point kinematics

Tsukamoto et al. '95
Martyn, Blair '99

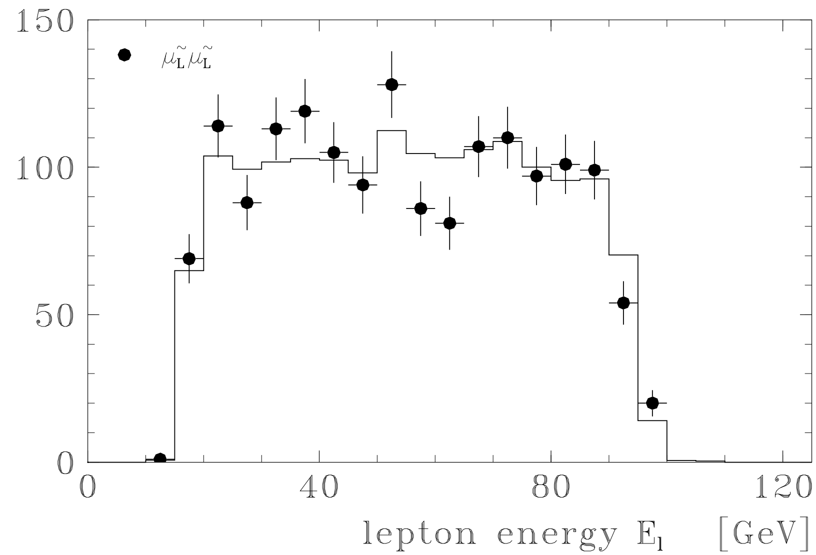
Two-body decay $\tilde{f} \to f\,\tilde{\chi}^0_j$ $\quad\to$ Flat energy spectrum for f
end points determine $m_{\tilde{f}}$ and $m_{\tilde{\chi}^0_1}$

Problem: Backgrounds, fake edges

$\tilde{\mu}_R\tilde{\mu}_R$ $\quad (m_{\tilde{\mu}_R} = 132$ GeV$)$



$\tilde{\mu}_L\tilde{\mu}_L$ $\quad (m_{\tilde{\mu}_L} = 176$ GeV$)$



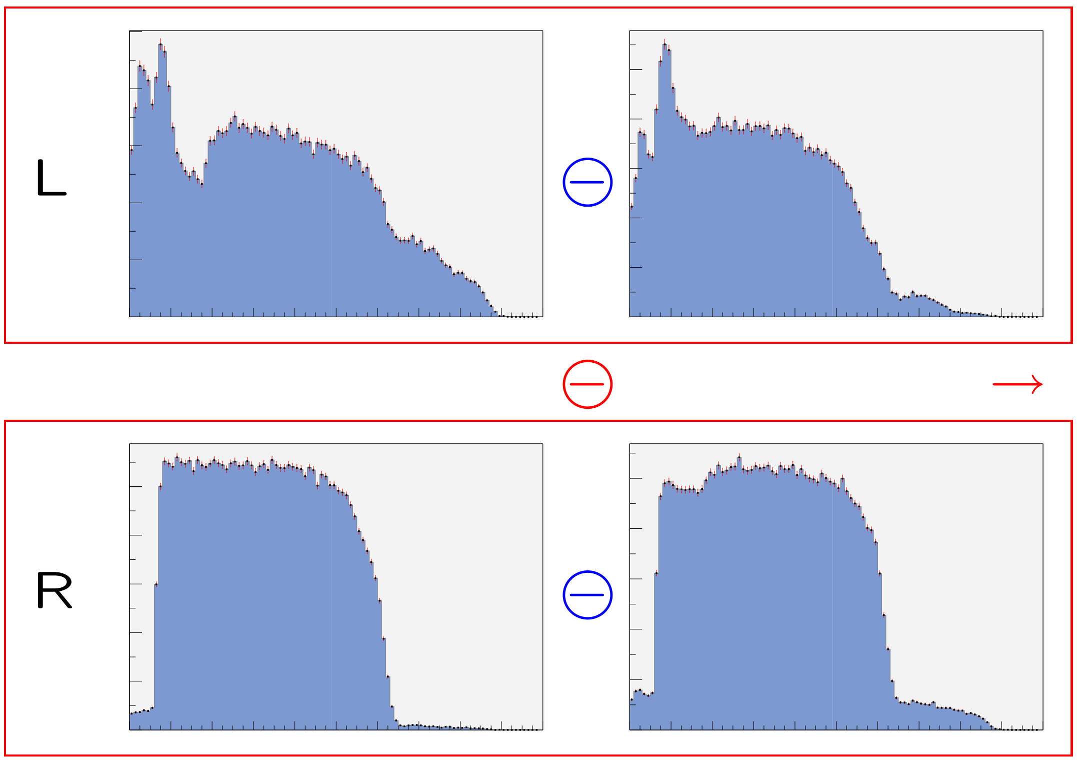
Subtraction of background in selectron production

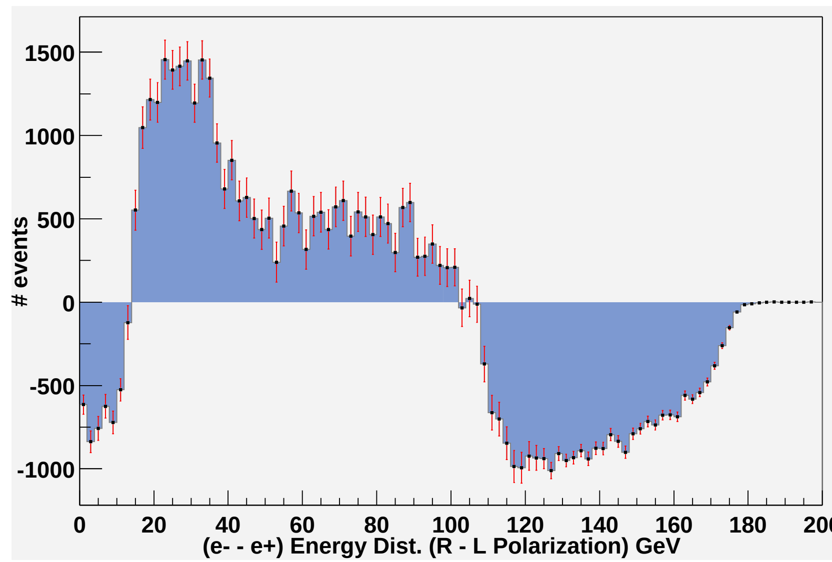
Dima et al. '02

Mixed selectron production $\tilde{e}_R^- \tilde{e}_L^+$ $\longrightarrow$ different distrib. for e^- and e^+

- Subtract e^- and e^+ distributions $\longrightarrow$ cancel backgrounds
- Subtract distributions for L/R pol. $\longrightarrow$ discriminate $\tilde{e}_R^- \tilde{e}_L^+$ and $\tilde{e}_R^+ \tilde{e}_L^-$

electron positron

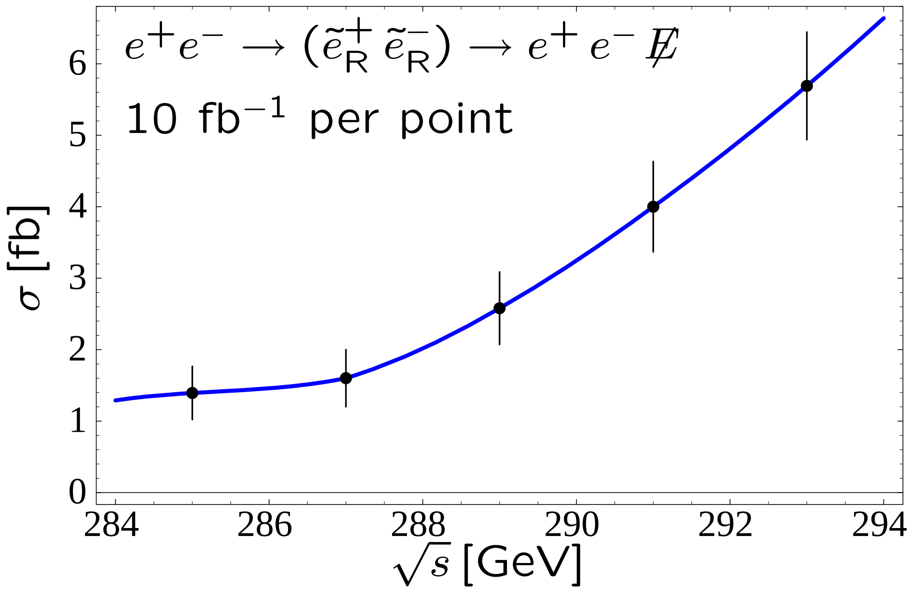


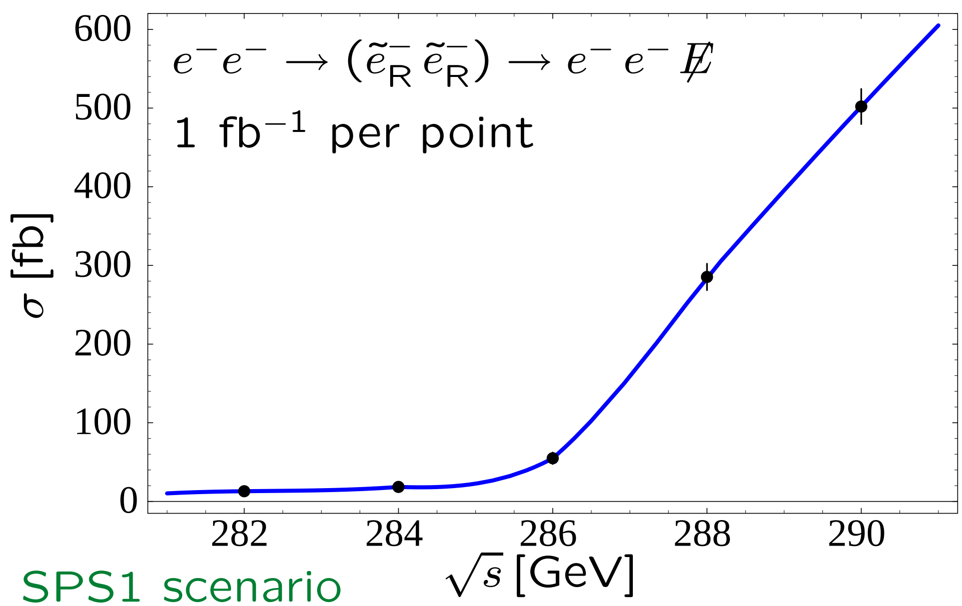


SPS1 scenario

$$m_{\tilde{e}_R} = 143 \pm 0.23 \text{ GeV}$$
$$m_{\tilde{e}_L} = 202 \pm 0.11 \text{ GeV}$$
$$m_{\tilde{\chi}_1^0} = 96 \pm 0.12 \text{ GeV}$$

Threshold scans





SPS1 scenario

Binned likelihood fit:

	$m_{\tilde{e}_R}$ [GeV]	$\Gamma_{\tilde{e}_R}$ [MeV]
$\tilde{e}_R^+ \tilde{e}_R^-$	$143.0^{+0.21}_{-0.19}$	150^{+300}_{-250}
$\tilde{e}_R^- \tilde{e}_R^-$	$143.0^{+0.048}_{-0.053}$	200^{+50}_{-40}

Precise predictions of excitation curves:

A.F., Miller, Zerwas '01

- Finite widths, gauge invariance
- Coulomb correction, ISR, beamstrahlung
- SM and SUSY backgrounds

Testing slepton mass nonuniversality

Baer et al '01

Precise mass measurements allow test of GUT-scale mass relations (e.g. mSUGRA)

→ talk of P.M.Zerwas in ∼10 min.

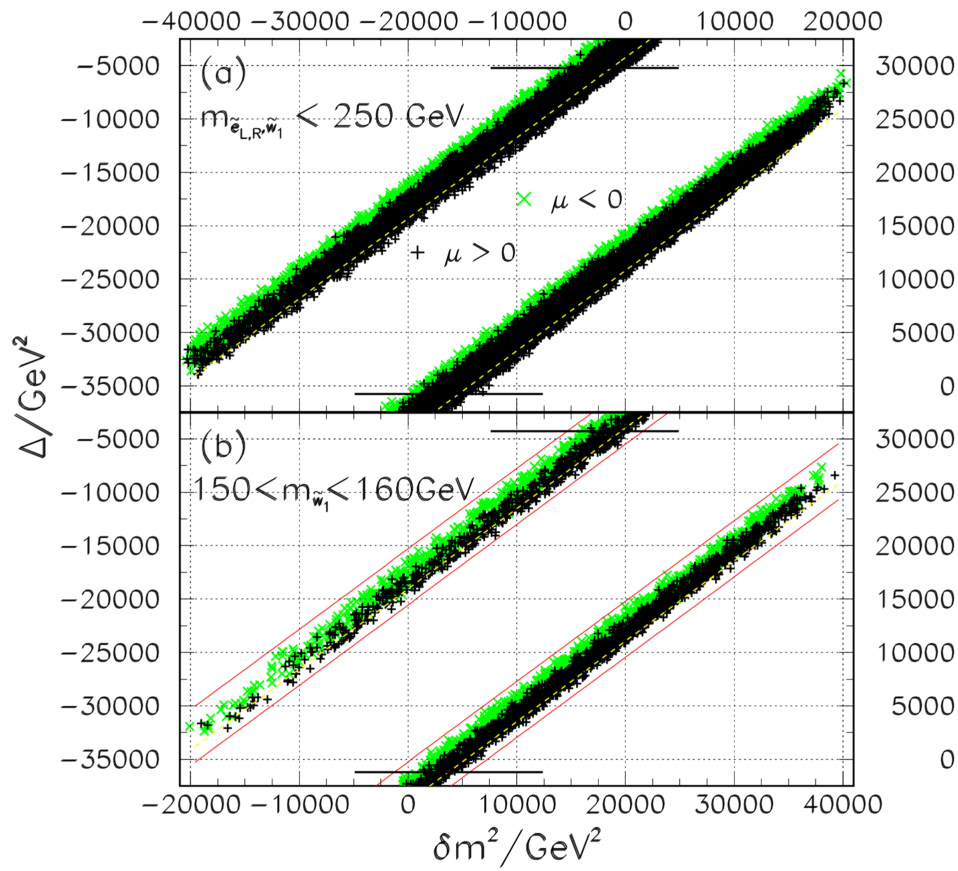
Test of slepton mass unification in mSUGRA-type models:

use quantity, based on 1-loop RGE:

$$\Delta = m^2_{\tilde{e}_R} - m^2_{\tilde{e}_L} + \frac{m^2_{\tilde{W}_1}}{2\alpha_2^2(m_{\tilde{W}_1})} \times \left[\frac{3}{11}\left(\alpha_1^2(m_{\tilde{e}}) - \alpha_1^2(M_{\rm GUT})\right) - 3\left(\alpha_2^2(m_{\tilde{e}}) - \alpha_2^2(M_{\rm GUT})\right)\right]$$

Strongly correlated with slepton mass nonuniversality

$$\delta m^2 \equiv m^2_{\tilde{e}_R}(M_{\rm GUT}) - m^2_{\tilde{e}_L}(M_{\rm GUT})$$



possible to probe $|\delta m^2| \gtrsim 5000\,\mathrm{GeV}^2$

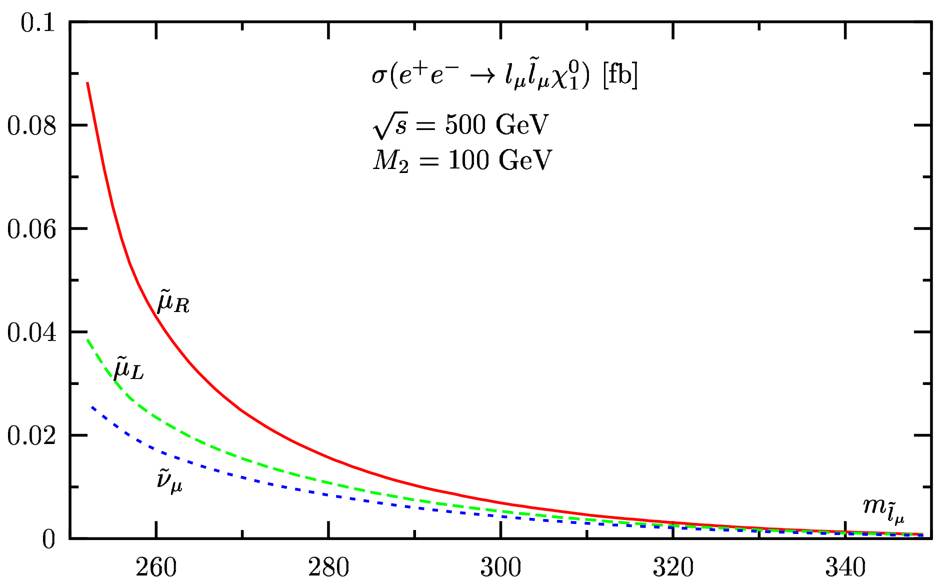
Single slepton production

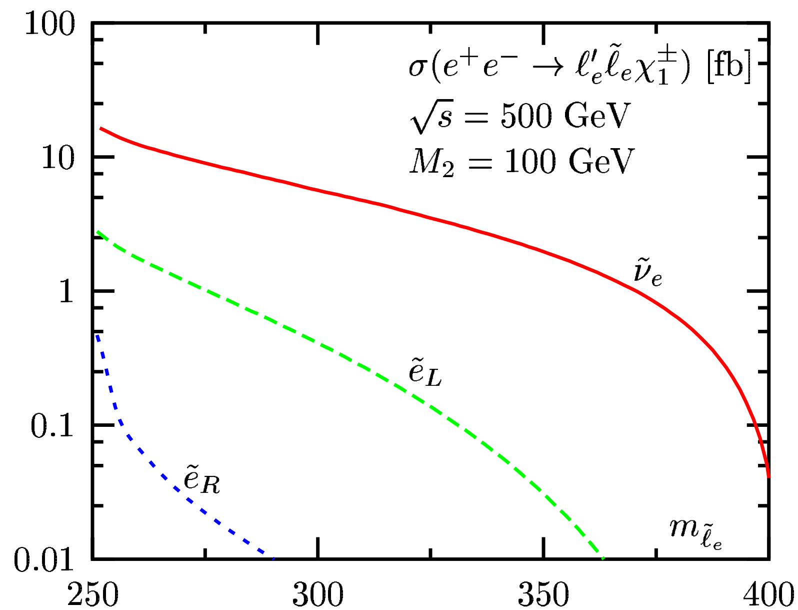
Datta, Djouadi '01   Datta, Djouadi, Mühlleitner '02

For $\sqrt{s} < 2m_{\tilde{l}}$ slepton pairs can only be produced off-shell:

$$e^+e^- \to \tilde{l}_i\,\tilde{l}_i^* \to \begin{cases} \tilde{l}_i\; l\;\; \tilde{\chi}_j^0 \\ \tilde{l}_i\,\nu_l\,\tilde{\chi}_k^- \end{cases}$$

With high luminosity (500 fb^{-1}) sleptons can be discovered with $m_{\tilde{l}} - \sqrt{s}/2 \sim \mathcal{O}(10\ \text{GeV})$





Determination of $\tan\beta$ from $\tilde{\tau}$ decay

Boos et al. '02

Production and decay of $\tilde{\tau}$ sensitive to $\tan\beta$, in particular for large $\tan\beta$

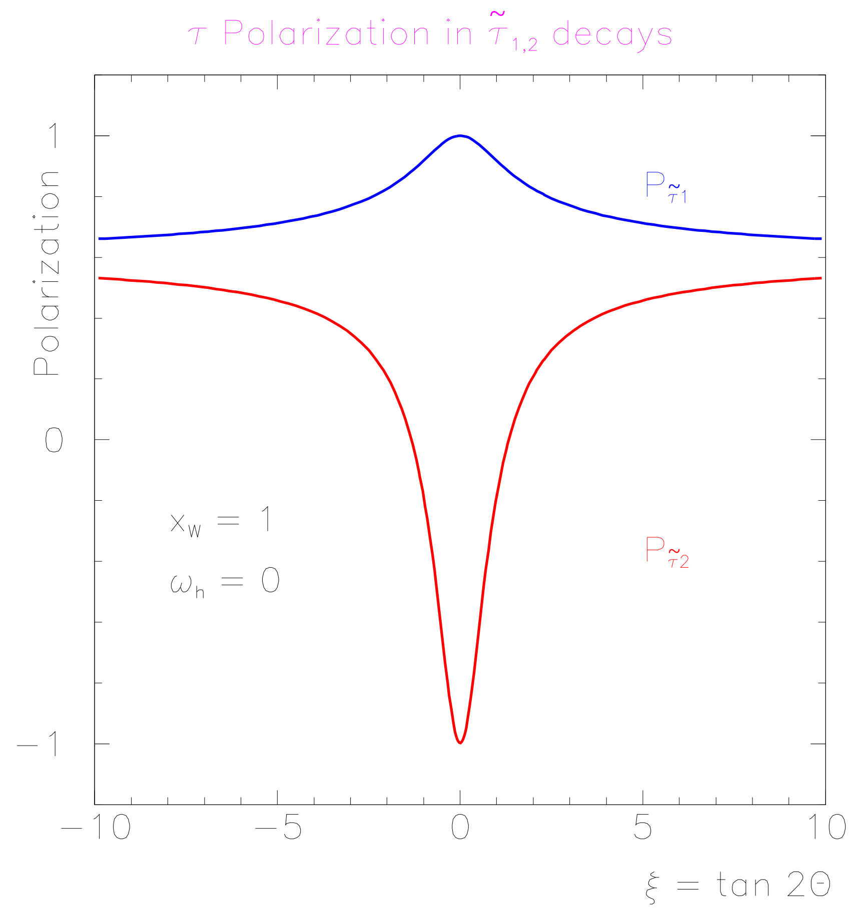
- $\tilde{\tau}_L$–$\tilde{\tau}_R$ mixing: $$\mathcal{M}^2_{\tilde{\tau}} = \begin{pmatrix} m_\tau^2 + M_L^2 + D_L & m_\tau(A_\tau - \mu\tan\beta) \\ m_\tau(A_\tau - \mu\tan\beta) & m_\tau^2 + M_R^2 + D_R \end{pmatrix}$$
- Higgsino Yukawa coupling $\propto 1/\cos\beta$
- Neutralino sector weakly depends on $\tan\beta$ for large $\tan\beta$

Use τ polarization in decay $\tilde{\tau}^-_{1,2} \to \tau^-_{L,R}\tilde{\chi}^0_1$ as probe of $\tan\beta$

Nojiri '95

For $\tan\beta > 30$:

$\delta\tan\beta/\tan\beta \sim 10\%$



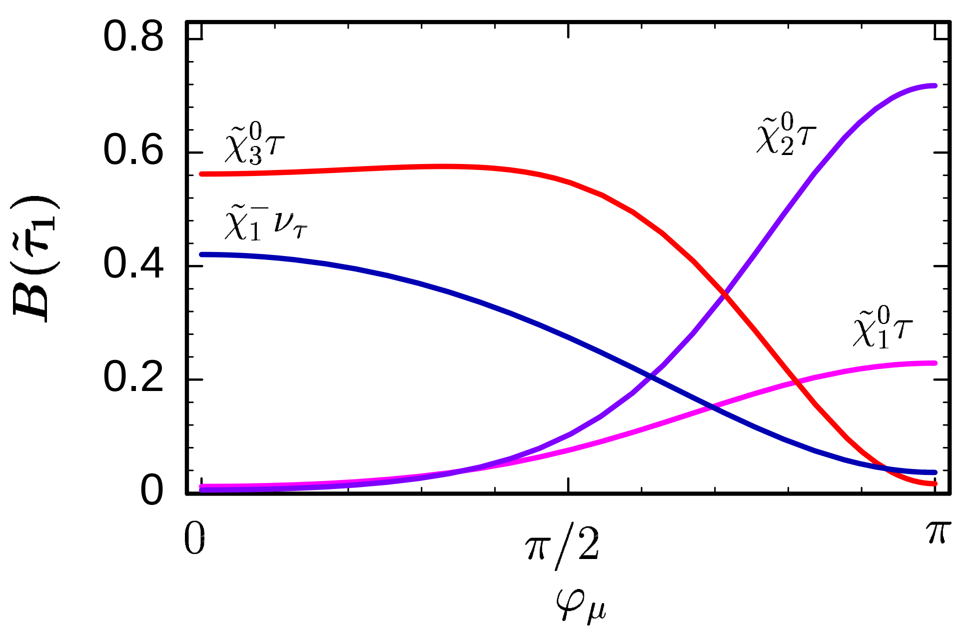
CP-violation in $\tilde{\tau}/\tilde{\nu}_\tau$ production and decay

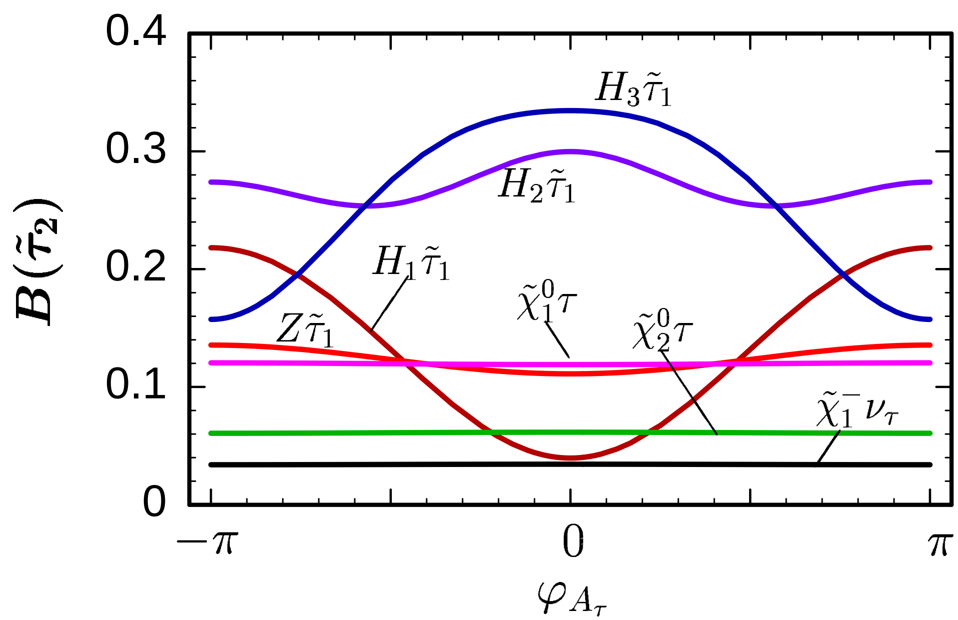
Bartl, Hidaka, Kernreiter, Porod '02

Complex phases possible for μ, A_τ and bino mass parameter M_1

→ **Effect on**

masses of $\tilde{\tau}_i$, $\tilde{\chi}^0_j$, $\tilde{\chi}^\pm_k$,
$\sigma(e^+e^- \to \tilde{\tau}_i\tilde{\tau}_j)$,
$B(\tilde{\tau} \to \tau\tilde{\chi}^0_j)$, $B(\tilde{\tau} \to \nu_\tau\tilde{\chi}^-_k)$, $B(\tilde{\tau}_2 \to \tilde{\tau}_1\, Z/A^0/h^0/H^0)$,
$P_\tau(\tilde{\tau} \to \tau\tilde{\chi}^0_j)$





Over-constrained set of observables to determine parameters

$\tan\beta$	3	30	
$M^2_{\tilde{\tau}_L}$ [GeV^2]	$(225 \pm 2) \cdot 10^2$	$(225 \pm 6) \cdot 10^2$	$\mathcal{O}(\%)$
$m^2_{\tilde{\tau}_R}$ [GeV^2]	$(1225 \pm 4) \cdot 10^2$	$(1229 \pm 7) \cdot 10^2$	$< 1\%$
$\Re e\, A_\tau$ [GeV]	-8 ± 180	8 ± 55	5–10%
$\Im m\, A_\tau$ [GeV]	-800 ± 70	-800 ± 21	
$\Re e\, \mu$ [GeV]	249.9 ± 0.26	249.9 ± 0.6	$\lesssim 1\%$
$\Im m\, \mu$ [GeV]	2.4 ± 1.7	-0.2 ± 3.8	
$\tan\beta$	2.99 ± 0.03	29.9 ± 0.7	$\mathcal{O}(\%)$
$\Re e\, M_1$ [GeV]	140.9 ± 0.2	140.6 ± 0.6	$\lesssim 1\%$
$\Im m\, M_1$ [GeV]	-0.7 ± 3.4	0.16 ± 1.0	
M_2 [GeV]	280.0 ± 0.3	280 ± 1	$< 1\%$

Very good accuracy for all parameters if decay $\tilde{\tau}_2 \to \tilde{\tau}_1 +$ Higgs kinematically allowed.

Light scalar tops

Nowak, Sopczak '02

$\tilde{t}_1$ can be lightest scalar quark
$\longrightarrow$ decay into top not possible

Most important channels:

$$\begin{aligned} \tilde{t}_1 \; &\longrightarrow c\, \tilde{\chi}^0_0 \\ &\longrightarrow b\, \tilde{\chi}^+_1 \\ &\longrightarrow b\, l\, \tilde{\nu}_l \end{aligned}$$

Beam polarization to disentangle stop parameters:

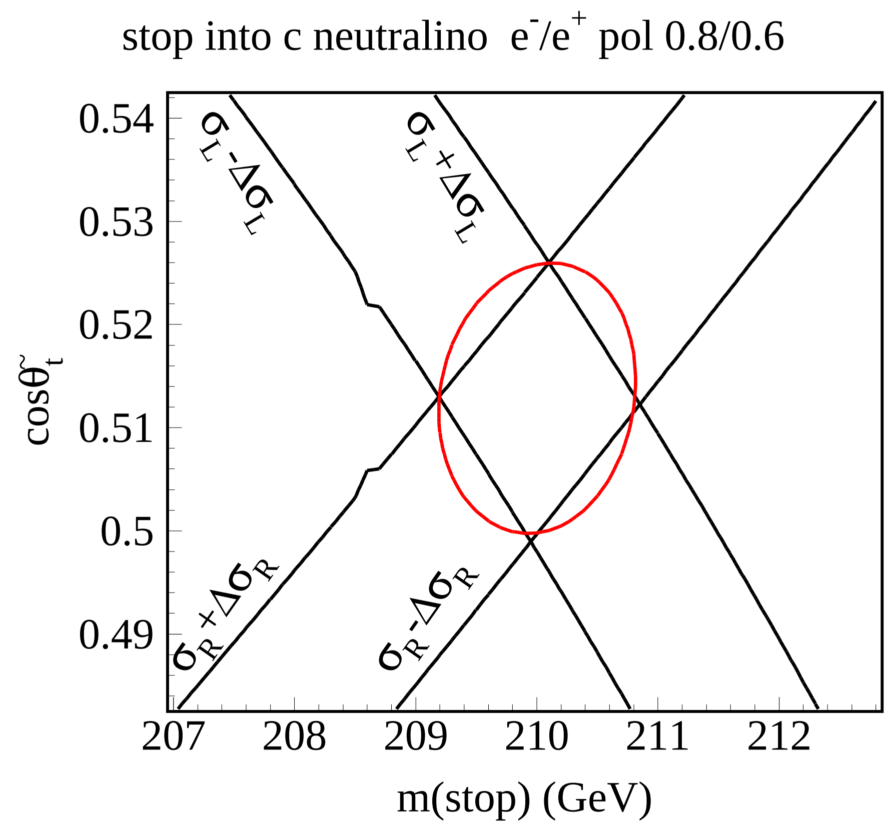
$$\begin{aligned} P_{e^-}/P_{e^+} &= -0.8/0.6 \quad \longrightarrow \sigma_{\mathrm{L}} \\ &= 0.8/-0.6 \quad \longrightarrow \sigma_{\mathrm{R}} \end{aligned}$$

Iterative discriminant analysis including backgrounds:

$$\begin{aligned} \Delta m_{\tilde{t}_1} &= 0.95 \text{ GeV} \\ \Delta \cos\theta_{\tilde{t}} &= 0.0125 \end{aligned}$$

SPS5 scenario

$m_{\tilde{t}_1} = 210$ GeV
$\cos\theta_{\tilde{t}} = 0.513$
$m_{\tilde{\chi}^0_1} = 121$ GeV



Bosonic stop/sbottom decays

Hidaka, Bartl '01

- Bosonic decays,

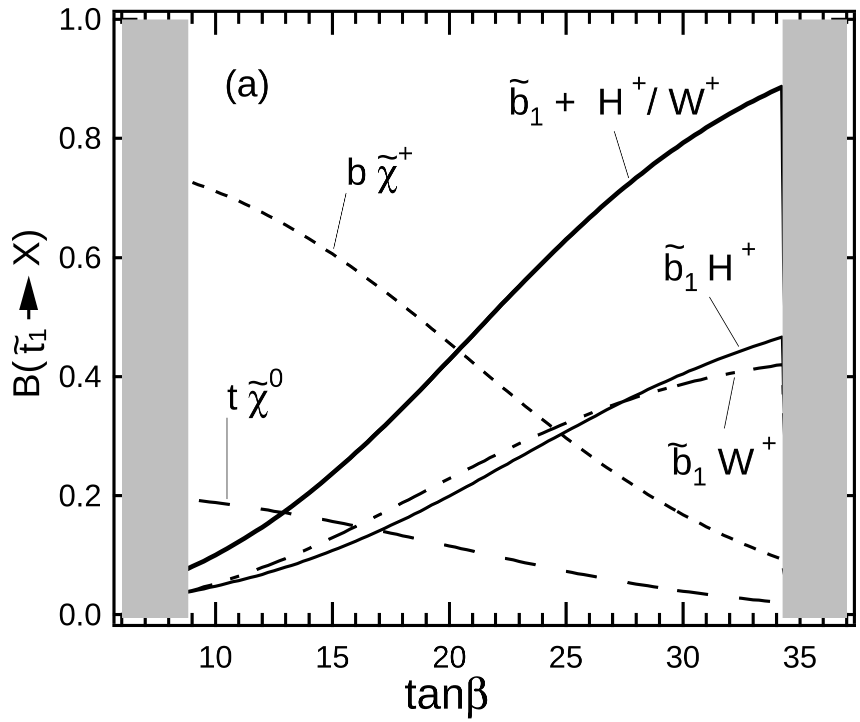
  $\tilde{t}_1 \to \tilde{b}_1 + (H^+$ or $W^+)$
  $\tilde{b}_1 \to \tilde{t}_1 + (H^+$ or $W^+)$

  can be dominant
  due to large Yukawa couplings
  and mixings of $\tilde{t}_1$, $\tilde{b}_1$

- Different decay distributions compared to fermionic decays

- **Large** SUSY-QCD corrections, dominant effects included by SUSY-QCD running of $q/\tilde{q}$ parameters

$\rightarrow$ Important effect on search for $\tilde{t}_1$, $\tilde{b}_1$ and MSSM parameter determination



$M_{\tilde{Q}} = \quad 600$ GeV
$\mu = -700$ GeV
$A_t = A_b = -800$ GeV

Conclusions

SUSY precision measurements

→ Test of supersymmetry relations

→ Unravel underlying breaking mechanism

Wish list for sparticle hunters:

- Quantum numbers, couplings $\surd$
- Masses $\surd$
- Sparticle mixing $\surd$
- $\tan\beta$ and trilinear couplings $\surd$
- CP violation $\surd$

Still more work to do!